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RESEARCH NOTE

Notes on the natural history and ecology of *Inflectarius magazinensis* (Pilsbry and Ferriss, 1907) (Gastropoda: Polygyridae), the Magazine Mountain Shagreen

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Abstract: *Inflectarius magazinensis* (Pilsbry and Ferriss, 1907), the Magazine Mountain Shagreen, is an endemic land snail found only on Magazine Mountain, Arkansas, U.S.A. This species was given the status of threatened in 1989, but was removed from the threatened list by the United States Fish and Wildlife Service in June 2013 due to apparent stability of the population within its known habitat. *Inflectarius magazinensis* is a rupicolous species inhabiting talus areas of Savanna sandstone. Populations occur from approximately 670 m to 790 m on the north and west sides of Magazine Mountain. Our study was designed to gather information regarding basic natural history and ecology knowledge for this species. We examined both known localities and sites where there were no historical records for the presence of *I. magazinensis* but suitable habitat was present. We found that this species is restricted to only the north- and west-facing slopes of Magazine Mountain. Due to its restricted habitat preferences, the total range of this species amounts to approximately nine hectares on the upper slopes of the mountain. Because *I. magazinensis* is endemic to Magazine Mountain and restricted to upper elevations, it should be monitored on a regular basis. Due to levels of uncertainty in terms of climate change, pollution, and disturbance (both natural and anthropogenic), habitat health should be taken into consideration as a metric used for monitoring the stability and long-term viability of this species.

Key words: food habits, Arkansas, Magazine Mountain, rare land snail

The land snails of Arkansas have been overlooked and are poorly represented in the scientific literature. The first papers concerning Arkansan Gastropoda examined species distributions across the entire state, as well as within certain regions in the state (Sampson 1893, Pilsbry 1903, Pilsbry and Ferriss 1906). Most studies have been compilations for certain localities within the state (Hubricht 1967, Hubricht 1972, Gordon 1980, Coles and Walsh 1999, Walsh and Coles 2002) with the exception of Solem (1976) who commented on the genus *Polygyrid* Because so little research has been done on the molluscan fauna of Arkansas, basic population and life history information, especially for rare species, is nonexistent.

Inflectarius magazinensis (Pilsbry and Ferris, 1907) is a rupicolous (*i.e.*, rock inhabiting) species of land snail endemic to Magazine Mountain, Arkansas. It was originally listed as threatened in the late 1980's (United States Fish and Wildife Service 1989) based on a preliminary status report (Caldwell 1986), but has since been proposed for removal from the threatened status (Davidson 2012) and subsequently removed (Arkansas Ecological Services Field Office 2013) largely because of apparent population stability, investigations into habitat requirements, and proposed continuation of monitoring (Caldwell *et al.* 2010, United States Fish and Wildife Service 2013). However, certain aspects of natural history and basic ecology remain unknown for this species.

This study was initiated to define *Inflectarius magazinensis*' range and obtain natural history information for use in the Revised Recovery Plan. Since it so closely resembles two other species, *I. edentatus* (Sampson, 1889) and *I. inflectus* (Say, 1821), they were included in the study to document the distinctness of *I. magazinensis*. The ranges of the three species and some habitat information are given in Hubricht (1985). *Inflectarius inflectus* is common throughout the eastern United States in a variety of habitats. *Inflectarius edentatus* is primarily found on wooded slopes north of Magazine Mountain in eastern Oklahoma, northwestern Arkansas, and southern Missouri (Pilsbry 1903, Pilsbry and Ferriss 1907, Hubricht 1972).

The primary objective of this study was to delineate and map the range of *Inflectarius magazinensis*. Additionally, we wished to determine the ecology and habitat associations (*i.e.*, vegetation and land snail cohorts) of this species by examining sites where the species was known to be present and sites where

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Table 1. Mean greater diameter measurements and numbers for *Inflectarius* species found during this study.

Species	Number	Mean Greater Diameter
Inflectarius edentatus (Sampson, 1889)	34	11.65
Inflectarius inflectus (Say, 1821)	69	10.31
Inflectarius magazinensis (Pilsbry and Ferris, 1907)	45	12.76
Undescribed *Inflectarius* sp.	41	11.12

conditions were suitable but no historical records of its presence were available. A secondary objective was to document the reproductive habits of this species as well as to record food sources, feeding behaviors, and principal activity periods.

Survey periods were 8–19 May 2007, 10–12 July 2007, 30 September–5 October 2007, and 5–14 May 2008. On Magazine Mountain, 40 study plots (20 north side and 20 south side) were established to record habitat parameters such as vegetation, biotic, abiotic, and physical attributes of known and potential sites. The surrounding areas of Poteau, Short, and Sugar Loaf Mountains were surveyed for potential habitat. Mount Nebo (535 m elevation) and Petit Jean Mountain (360 m elevation) were chosen for more intense surveys due to the presence of core habitats, similar to that of Magazine Mountain (839 m elevation).

All study sites were located in the central portion of the Arkansas River valley ecoregion (Level III) and the Scattered High Ridges and Mountains ecoregion (Level IV) (Woods *et al.* 2004). Vegetated Savanna Sandstone rock talus is a dominant feature of this region (Vere 1986) and is the preferred habitat of *Inflectarius magazinensis* (Caldwell 1986).

Study plots were circular with a 10 m radius (314 m^2 in area). Within each plot, data concerning the following variables was collected: percent canopy cover, duff accumulation (*i.e.*, cm of organic soil horizon), percent bare ground, percent leaf litter, percent rock, percent coarse woody debris (CWD), aspect, slope, tree species present, shrub species present, forest community type, basal area (BA), and snail associates. Percent canopy cover, percent bare ground, percent leaf litter, percent rock, rock characteristics, and percent coarse woody debris (by decay class) was determined by ocular estimation.

Tree and shrub vegetation was sampled on both north and south slope talus of Magazine Mountain. Vegetation was sampled using the point-quarter method (Cottam and Curtis 1956). This method was modified by having a 4 x 4 m sampling plot for shrubs (Caplenor 1968). Trees were defined as having a diameter at breast height (DBH) equal to or greater than 10 cm. Any woody stem plant having a diameter less than 10 cm was considered a shrub. Data collected were used to determine importance values (IV) (*i.e.*, the summation of relative frequency, relative density, and relative coverage [scale 0–300]) of each species.

Taylor digital max/min thermometers were set out 5 May and removed 11 May 2007. This yielded recordings for six, 24 hour periods. Daily maximum and minimum temperatures were determined for ground surface, within rock crevices, and for the atmosphere (50 cm above the ground). Fifteen thermometers were placed on the south slope talus where two were used to obtain ground and atmospheric temperature and 13 were used for rock crevice temperature. Fourteen thermometers were placed on the north slope talus where two were for recording ground and atmospheric temperature and 12 were for recording rock crevice temperature.

Terrestrial gastropod species present at each plot were determined by hand collection of larger shells, timed searches (20 person minutes) within microhabitats present (*i.e.*, leaf litter, rock talus, CWD, exfoliating bark present on standing snags and downed woody material, hollow trees and forks of trees where detritus had accumulated, damaged trees excreting sap, and cliff line features), and through laboratory searches of one liter bags filled with appropriate microhabitat substrate material. A minimum of one bag was collected from each quarter section, equaling four bags per plot. All litter was inspected for larger snails before being placed in bags to assure no collection of *Inflectarius magazinensis*. Night surveys were conducted to assess activity periods and to observe feeding behavior. The following measurements were taken in millimeters on each of the three target species when

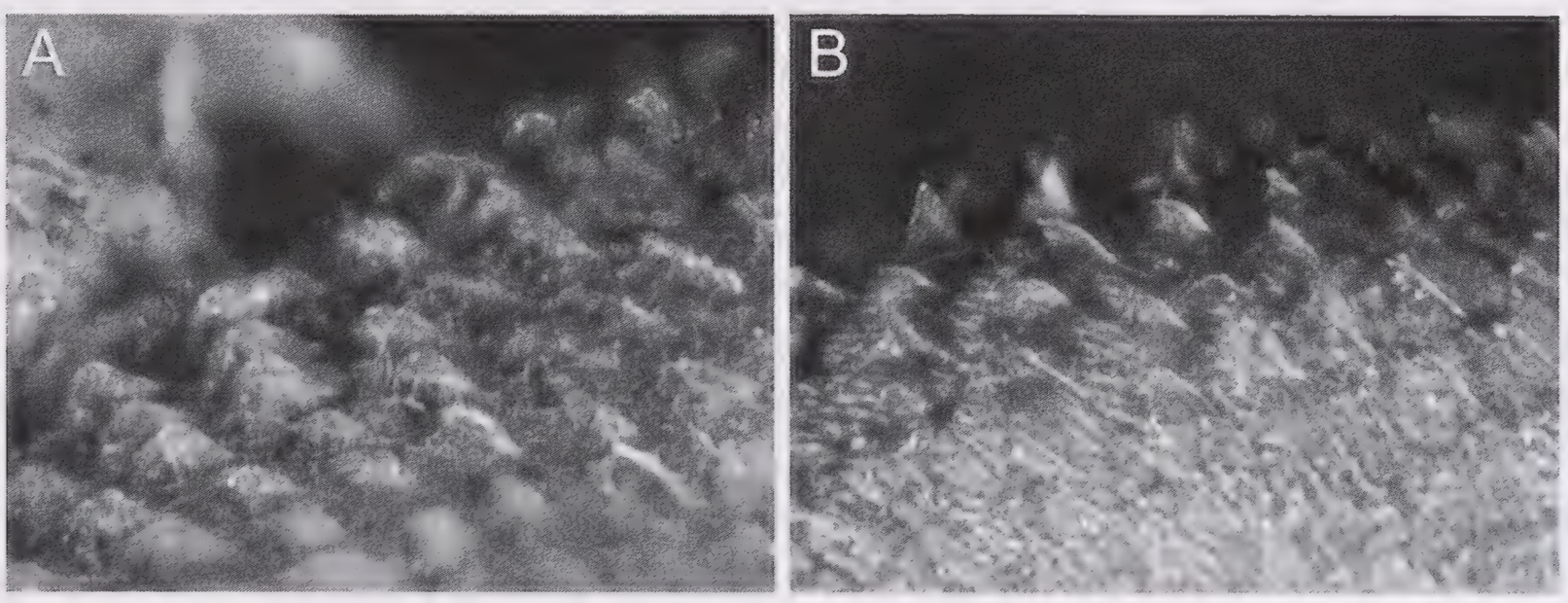

Figure 1. Periostracal processes of **A,** *Inflectarius magazinensis* compared to **B,** *Inflectarius inflectus*. Total magnification 250X. (Color shown in electronic version only).

possible: greater diameter (GD) (measured from the aperture all the way across the shell), lesser diameter (LD) (diameter perpendicular to the GD), umbilicus diameter (UD), and whorl count (W) (every full whorl to the right of the apex).

Individuals of *Inflectarius inflectus* in which aperture teeth are reduced can be very similar to *I. magazinensis*. *Inflectarius magazinensis* is the largest of the three species, followed by *I. edentatus*, and *I. inflectus* (Table 1). Periostracal processes of *I. inflectus* and *I. magazinensis* are substantially different from one another (Fig. 1). *Inflectarius magazinensis* has semi-lunar processes while *I. inflectus* processes are more delta- or tooth-shaped. Periostracal processes of *I. edentatus* and *I. magazinensis* are identical. However, these two species are not sympatric. The sizes of *I. edentatus* and *I. magazinensis* are comparable and the shells are indistinguishable.

No *Inflectarius magazinensis* were found outside of Magazine Mountain. Populations occur on the upper slopes of the north and west sides of Magazine Mountain within a 120 m range. Populations were documented to occur on the north-facing slopes just below the cliff line at approximately 670 m and on the west-facing slopes at approximately 790 m. Incorporating all known localities, the total range of this species is approximately nine hectares in area.

Within the tree layers of the study site, *Tilia americana*, *Acer saccharum*, and *Fraxinus americana* were found only in north slope talus (Table 2). *Quercus rubra* had the highest IV of all tree species found in the north slope talus (IV = 1.09) but was fourth highest in the south slope talus (IV = 0.21) (Table 2). Within the shrub layers of the north and south slope, *Ribes cynosbati* was found only in the north slope talus and had the second highest IV of any north slope talus shrub (Table 2).

The number of max/min temperature readings taken for each temperature comparison between slopes are as follow: rock crevice north slope 114, rock crevice south slope 131; atmospheric north slope 15, atmospheric south slope 13; and ground north slope 12, ground south slope 12. An analysis of variance comparison of rock crevice, atmospheric, and ground temperatures between north and south slopes found no significant differences for maximum temperatures. However, significant differences were found for minimum temperatures. Ground minimum temperatures on the north slope were 3.1 °C lower than on the south slope ($P = 0.01$). Atmospheric minimum temperatures on the north slope were 2.9 °C lower than on the south slope ($P = 0.005$). Rock crevice temperatures were found 2 °C cooler on the north slope ($P < 0.0001$).

Euconulus fulvus (Müller , 1774), *Vertigo milium* (Gould, 1840), *V. tridentata* Wolf, 1870, *Glyphyalinia lewisiana* (G. H. Clapp, 1908), and *Millerelix dorfeuilliana* (I. Lea, 1838) were found only on the south slope talus where *Inflectarius magazinensis* does not occur (Table 3). *Neohelix divesta* (Gould, 1848), *Zonitoides arboreus* (Say, 1816), and immature *Succineidae* sp.

Table 2. Importance values for trees and shrubs found in study plots on both the north and south facing slopes of Magazine Mountain.

Species	North Slope	South Slope
Trees		
Acer saccharum	0.08	
Asimina triloba		0.06
Carya spp.	0.32	0.95
Celtis sp.		0.07
Fraxinus americana	0.05	
Juglans nigra	0.09	0.20
Nyssa sylvatica	0.18	0.32
Ostrya virginiana	0.28	0.01
Quercus alba		0.61
Quercus alba	0.24	
Quercus muehlenbergii	0.11	
Quercus rubra	1.09	0.21
Quercus velutina		0.20
Robinia pseudoacacia	0.14	0.19
Sassafras albidum	0.18	0.14
Tilia americana	0.22	
Shrubs		
Acer rubrum		0.04
Aesculus glabra	0.02	
Amelanchier arborea	0.08	0.02
Aralia spinosa	0.07	
Asimina triloba		0.42
Carya spp.	0.13	0.24
Castanea pumila	0.05	0.04
Celtis sp.		0.05
Cercis canadensis		0.23
Chionanthus virginicus	0.02	
Cornus florida		0.10
Corylus americana		0.18
Dioscorea villosa	0.02	
Fraxinus americana	0.02	
Hydrangea arborescens	0.04	
Nyssa sylvatica	0.15	0.30
Ostrya virginiana	0.62	
Quercus alba		0.13
Quercus rubra	0.16	0.03
Ribes cynosbati	0.47	
Robinia pseudoacacia	0.16	0.26
Rubus flagellaris		0.14
Rubus occidentalis	0.05	
Rubus sp.	0.02	
Sassafras albidum	0.29	0.30
Smilax spp.	0.02	0.12
Tilia americana	0.04	
Ulmus sp.	0.02	
Vaccinium sp.	0.36	
Viburnum prunifolium		0.05
Vitis sp.	0.17	0.36

Table 3. Abundance (ABD) and relative frequencies (RF) of land snails collected from leaf litter sample bags on north and south slopes of Magazine Mountain. Boldface indicates micro-snail (< 5 mm in diameter). Numbers in parentheses represent abundances.

Species	North Slope		South Slope	
	ABD	RF	ABD	RF
Anguispira strongylodes (Pfeifer, 1854)	26	0.049	2	0.006
Carychium exile H.C. Lea, 1842	32	0.061	43	0.130
Discus patulus (Deshayes, 1830)	17	0.032	21	0.063
Euconulus fulvus (Müller, 1774)			10	0.030
Gastrocopta contracta (Say, 1882)	8	0.015	4	0.012
Gastrocopta pentodon (Say, 1821)	41	0.078	12	0.036
Glyphyalinia indentata (Say, 1823)	5	0.009	8	0.024
Glyphyalinia lewisiana (Clapp, 1908)			26	0.078
Glyphyalinia wheatleyi (Bland, 1883)	31	0.058	27	0.081
Guppya sterkii (Dall, 1888)	37	0.070	38	0.114
Haplotrema concavum (Say, 1821)	25	0.047	9	0.027
Hawaiia minuscula (A. Binney, 1840)	1	0.001	3	0.009
Helicodiscus parallelus (Say, 1817)	10	0.019	14	0.042
Inflectarius inflectus (Say, 1821)	39	0.074	6	0.018
Mesomphix cupreus (Rafinesque, 1831)	37	0.070	4	0.012
Millerelix dorfeuilliana (I. Lea, 1838)			1	0.001
Mesodon zaletus (A. Binney, 1837)	50	0.095	10	0.030
Neohelix divesta (Gould, 1848)	3	0.006		
Patera binneyana (Pilsbry, 1899)	19	0.036	1	0.001
Punctum minutissimum (I. Lea 1841)	47	0.089	30	0.090
Paravitrea multidentata (A. Binney, 1840)	14	0.027	1	0.001
Succineidae (immature)	1			
Strobilops aeneus Pilsbry, 1926	3	0.006	6	0.018
Stenotrema labrosum (Bland, 1862)	17	0.032	3	0.009
Striatura meridionalis (Pilsbry and Ferriss, 1906)	41	0.078	12	0.066
Ventridens brittsi (Pilsbry, 1892)	11	0.021	1	0.001
Vertigo gouldi (A. Binney, 1843)	11	0.021	27	0.081
Vertigo milium (Gould, 1840)			3	0.009
Vertigo tridentata Wolf, 1870			1	0.003
Zonitoides arboreus (Say, 1816)	1	0.001	1	0.001
TOTALS	527	0.995	324	0.993

were the only species, outside of *I. magazinensis*, that occurred exclusively on the north slope talus (Table 3).

Inflectarius magazinensis were found during night surveys feeding on oak catkins, algal-covered rocks, and decaying *Quercus alba* (white oak) leaves. There were three documented feeding events, which represent the first report on the food habits of *I. magazinensis*.

During this study, breeding and egg-laying occurred in early May concomitant with the spring rains. No live individuals were found on the surface during night surveys or

under the leaf litter in July 2008. Night surveys conducted in October 2007 could not document surface activity but live individuals were found under the leaf litter. No egg masses were found in the October survey.

Prolonged drought or concomitant warming of temperatures, either through natural cycles or anthropogenically influenced (*i.e.*, climate change), could adversely affect species of land snails that occur at high elevations, such as *Inflectarius magazinensis* (Pearce and Paustain 2013). Most critically, nesting sites and egg masses may be compromised due to desiccation and lead to extinctions. Simulated laboratory experiments have shown this to be a consequence of climatic warming (Baur and Baur 1993). While adults may feed within the talus, surface feeding may be necessary to replenish calcium stores for egg deposition. If the habitat and food sources have been altered because of changes to climate, this raises questions about the long-term viability of this species. While there is still a great deal of uncertainty around the science of climate change, most models point toward dire consequences for biodiversity and skyrocketing extinction rates (Bellard *et al.* 2012). For a species with narrow ranges, like *I. magazinensis*, forecasts such as this are very grim. Consequently, it would be wise to err on the side of caution and continuously monitor and protect *I. magazinensis* habitat in order to maintain biodiversity and ecological integrity.

Our results are corroborated by the vegetative communities and land snail associates that are found on the north and south slopes of Magazine Mountain. Our data shows a much more mesic community present on the north slope (Table 2) where *Inflectarius magazinensis* occurs and suggests an inability to survive in drier conditions. Land snail associates present on the south slope reflect these drier conditions and belong to genera that tend to be adapted to more harsh circumstances (Nekola 2010). This indicates that changes in moisture regimes may lead to substantially altered communities, both in vegetation and land snail associates, as well as possible extinctions in rare species like *I. magazinensis*.

Previous studies hypothesized that other polygyrids were somewhat generalist in their food habits (Foster 1936, Blinn 1963). The most detailed research on food habits of any woodland polygyrid has been conducted on *Triodopsis platysayoides* (Brooks, 1933), another rupicolous federally threatened species (Dourson 2008). That species is a generalist and has been reported to feed on a variety of items, including dead camel crickets. *Inflectarius magazinensis* most likely mirrors these generalist food habits, therefore, food source is probably not limiting to this species. Woodland polygyrids likely sort food habits out by size cohorts (Foster 1936, Blinn 1963). Of course, micro-snails (< 5 mm in diameter) within the duff may feed on completely different items. We speculate this to be the case for juvenile *I. magazinensis.*

Because *Inflectarius magazinensis* is a species for which very little is known, systematically monitoring populations is a necessity in order to ensure population stability. While very little may be able to be done to protect this species from alterations induced by climate change, appropriate monitoring would allow for changes to be rapidly detected and necessary steps taken to preserve this species. A more proactive approach may be to monitor ecosystem health (*e.g.*, land snail community structure, vegetative communities, micro-climates) rather than focusing on one single species. Examining trends within the community would help predict potential perturbations and declines in habitat health that could adversely affect target species.

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